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**US 6575240 B1** **US 6497289 B1**  
**US 6470966 B2** **US 6085838 A**  
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**Fig. 1**

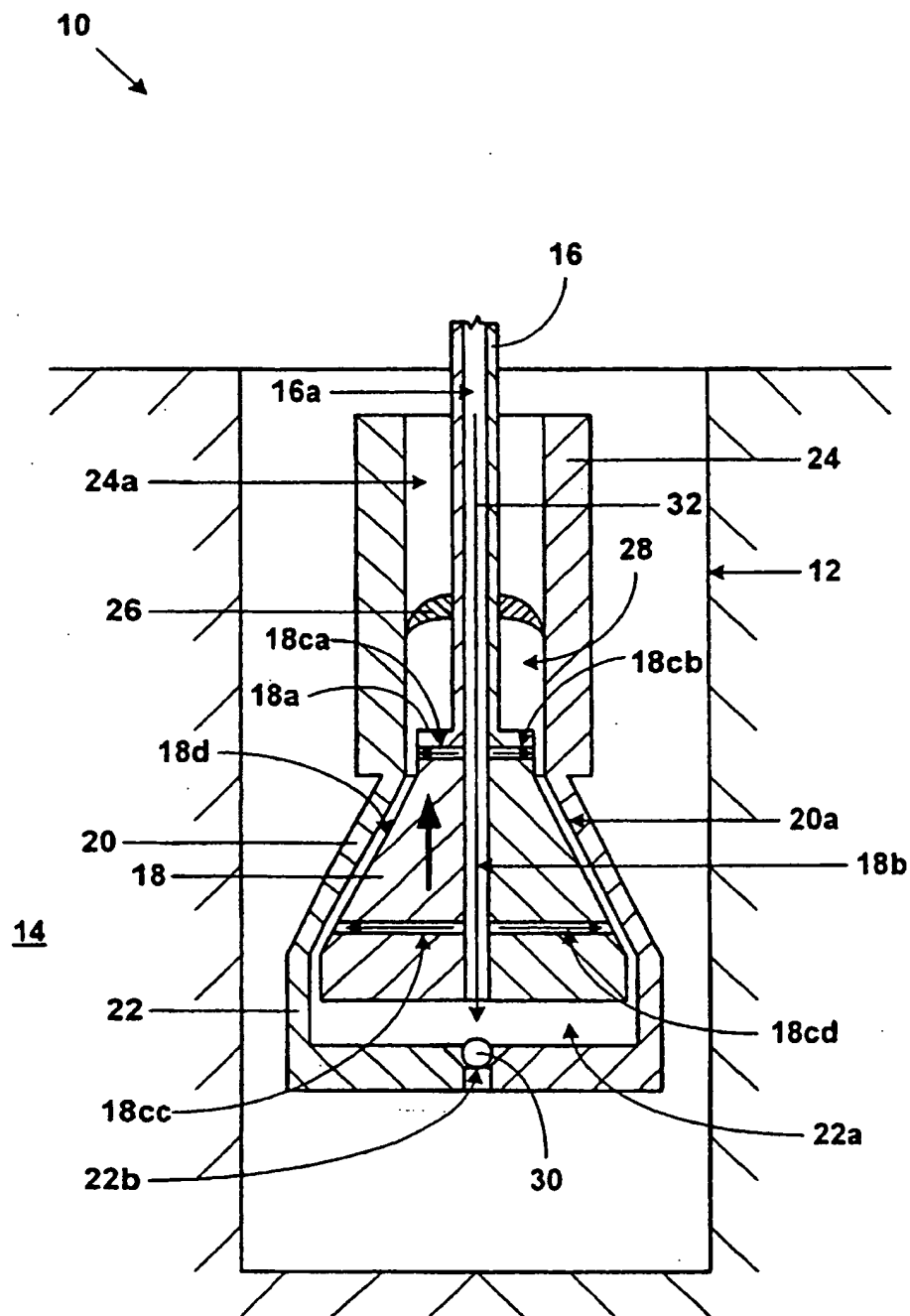
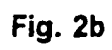


Fig. 2a



**Fig. 2b**

TYPICAL  
OPERATING  
PRESSURE  
FOR  
RADIAL  
EXPANSION  
OF TUBULAR

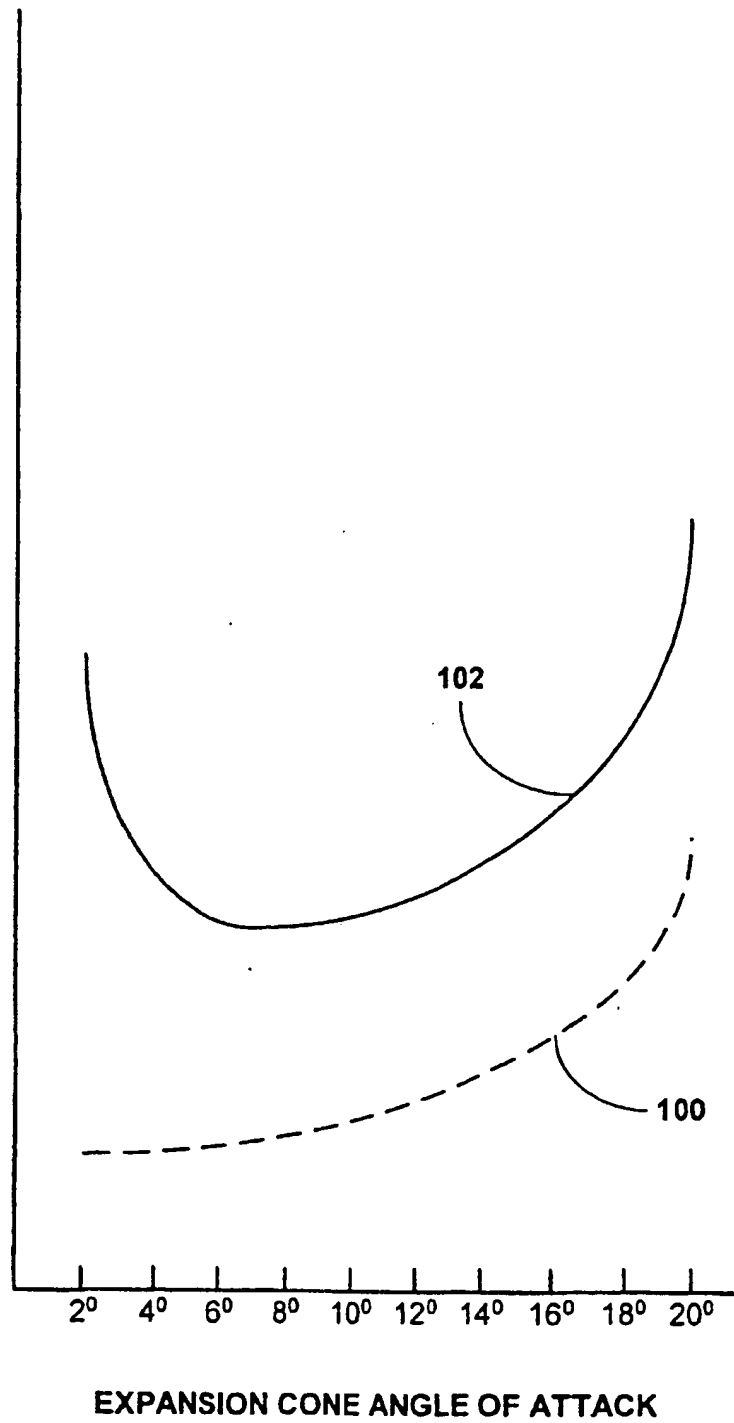


Fig. 3

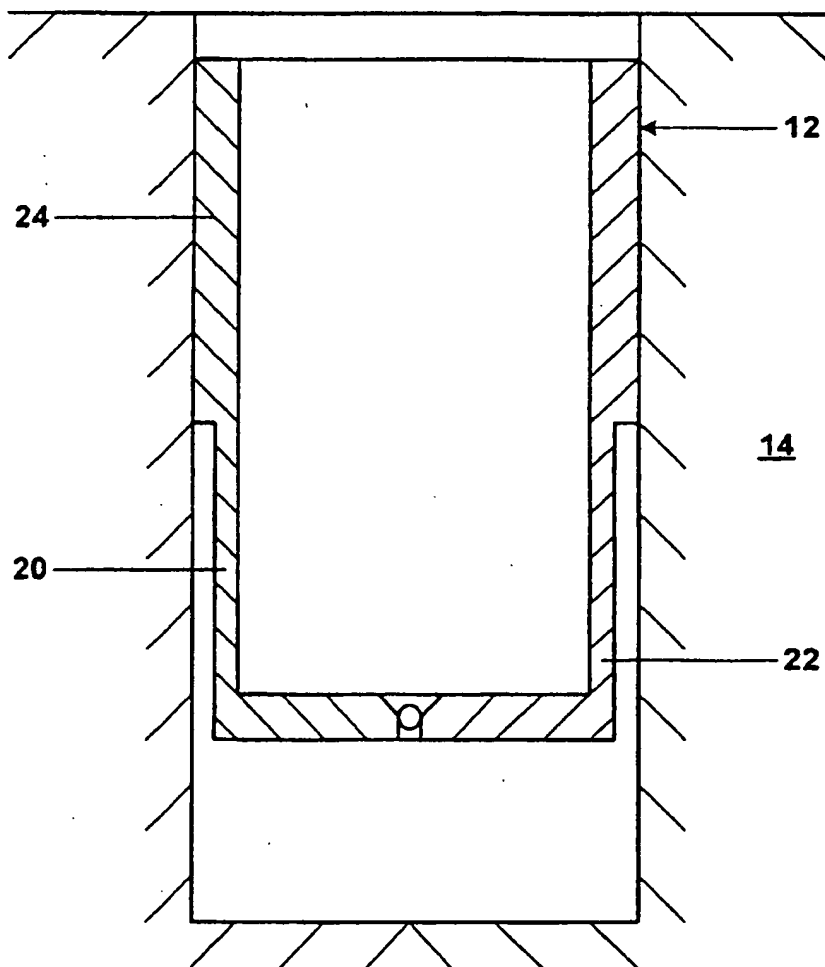


Fig. 4

**SYSTEM FOR RADially EXPANDING A TUBULAR MEMBER****Cross Reference To Related Applications**

5 The present application claims the benefit of the filing dates of (1) U.S. provisional patent application serial no. 60/391,703, attorney docket no 25791.90, filed on 6/26/2002, the disclosure of which is incorporated herein by reference

The present application is related to the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent no. 6,328,113, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on

2/20/2001, (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (26) U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, (28) U.S. provisional patent application serial no. 60/3318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (30) U.S. utility patent application serial no. 10/016,467, attorney docket no. 25791.70, filed on 12/10/2001, (31) U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001, (32) U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/2002, (33) U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/2002, (34) U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/2002, (35) U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/2002, (36) U.S. provisional patent application serial no. 60/387,486, attorney docket no. 25791.107, filed on 6/10/2002, and (37) U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/2002, the disclosures of which are incorporated herein by reference.

This invention relates generally to oil and gas exploration, and in particular to forming and repairing wellbore casings to facilitate oil and gas exploration and production.

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### **Background of the Invention**

Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are provided between the outer surfaces of the casings and the borehole wall to

seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings.

- 5 Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

10 The present invention is directed to overcoming one or more of the limitations of the existing processes for forming and repairing wellbore casings.

### **Summary of the Invention**

According to the present invention there is provided an apparatus for radially expanding and plastically deforming a tubular member, comprising:

- a tubular support member that defines a longitudinal passage;
- 15 an expansion device coupled to an end of the tubular support member that defines a longitudinal passage and one or more radial passages that extend from the longitudinal passage and extend to an outer surface of the expansion device;
- a tubular expansion launcher that receives the expansion device;
- an expandable tubular member coupled to an end of the tubular expansion
- 20 launcher; and
- one or more cup seals coupled to the tubular support member for sealingly engaging the interior surface of the expandable tubular member.

Preferably, the expansion device comprises a tapered outer surface and a non tapered outer surface; and

- 25 wherein at least one of the radial passages extends to the non tapered outer surface.

Preferably, at least one other of the radial passages extends to the tapered outer surface.

- 30 Preferably, the expansion device comprises a tapered outer surface and a non tapered outer surface;

wherein at least one of the radial passages extends to the non tapered outer surface; and

wherein at least one other of the radial passages extends to the tapered outer surface.

Preferably, the expansion device comprises a tubular expansion cone;  
wherein the tubular expansion launcher comprises a tubular expansion cone launcher that receives the tubular expansion cone; and

5 wherein the apparatus further comprises a tubular shoe coupled to an end of the tubular expansion cone launcher that defines a valveable longitudinal passage.

Preferably, the tubular expansion cone comprises a tapered outer surface and a non tapered outer surface; and

10 wherein at least one of the radial passages extends to the non tapered outer surface.

Preferably, at least one other of the radial passages extends to the tapered outer surface.

Preferably, the tubular expansion cone comprises a tapered outer surface and a non tapered outer surface;

15 wherein at least one of the radial passages extends to the non tapered outer surface; and

wherein at least one other of the radial passages extends to the tapered outer surface.

#### **Brief Description of the Drawings**

Fig. 1 is a fragmentary cross-sectional illustration of the placement of an apparatus for radially expanding a tubular member within a borehole that traverses a subterranean formation.

5 Figs. 2a and 2b are fragmentary cross-sectional illustrations of the apparatus of Fig. 1 after initiating the radial expansion and plastic deforming of the tubular member.

Fig.3 is a graphical illustration of the unexpected result provided during the operation of the apparatus of Figs. 2a and 2b during the radial expansion and plastic deformation of the tubular member.

10 Fig. 4 is a fragmentary cross-sectional illustration of the apparatus of Figs. 2a and 2b after completing the radial expansion and plastic deformation of the tubular member.

#### **Detailed Description of the Illustrative Embodiments**

In an exemplary embodiment, as illustrated in Fig. 1, an apparatus 10 is positioned within a borehole 12 that traverses a subterranean formation 14 that may include a source of hydrocarbons and/or geothermal energy.

15 In an exemplary embodiment, the apparatus includes a tubular support member 16 that defines a longitudinal passage 16a. An upper end 18a of a tubular expansion cone 18 that defines a longitudinal passage 18b, radial passages, 18ca and 18cb, that extend from the longitudinal passage to the outer surface of the tubular expansion cone 18 above a conical outer surface 18d, and radial passages, 18cc and 18cd, that extend from the longitudinal passage to the conical outer surface, is coupled to an end of the tubular support member 16. In this manner, fluidic materials may be conveyed from the passage 16a of the tubular support member 16 through the longitudinal passage 18b of the tubular expansion cone 18 and into the radial passages, 18ca, 18cb, 18cc, and 18cd, of the tubular expansion cone.

20 A tubular tapered expansion cone launcher 20 receives the outer conical surface 18d of the tubular expansion cone 18 within an interior passage 20a. In an exemplary embodiment, the interior surface of the tubular tapered expansion cone launcher 20 is a conical surface that is complementary shaped with respect to the outer conical surface 18d of the tubular expansion cone 18. An end of a tubular shoe 22 is coupled to an end of the tubular tapered expansion cone launcher 20 that defines an interior passage 22a and a valveable longitudinal passage 22b that may be adapted to receive a valve member such as, for example, a ball.

An end of an expandable tubular 24 that defines an internal passage 24a is coupled to another end of the tubular tapered expansion cone launcher 20. In an exemplary embodiment, the wall thickness of the expandable tubular 24 is greater than the wall thickness of the tubular tapered expansion cone launcher 20. In this manner, the initiation of the radial expansion of the expandable tubular member 24 is facilitated and the apparatus 10 may be positioned within wellbores 12 having tight radial clearances relative to the expansion cone launcher 20.

A resilient GuibersonJ sealing cup 26 is coupled to the exterior of the tubular support 16. In an exemplary embodiment, during operation of the apparatus 10, the sealing cup 26 engages the interior surface of the expandable tubular member 24 and thereby defines an annular chamber 28 between the exterior of the tubular support 16 and the interior of the expandable tubular member above the tubular expansion cone 18.

In an exemplary embodiment, as illustrated in Figs. 2a and 2b, during operation of the apparatus 10, a ball 30 is placed in the valveable passage 22b of the shoe 22 by injecting a fluidic material 32 into the apparatus 10 through the passages 16a and 18b. In this manner, the interior 22a of the tubular shoe 22 below the tubular expansion cone 18 and the annular chamber 28 above the tubular expansion cone below the GuibersonJ cup seal 26 may both be pressurized. In particular, continued injection of the fluidic material 32 into the apparatus 10 through the passages 16a and 18b will pressurize the interior of the tubular shoe 22 below the tubular expansion cone 18 as well as the annular chamber 28 above the tubular expansion cone below the GuibersonJ cup seal 26. As a result, the tubular expansion cone 18 will be displaced upwardly in the longitudinal direction relative to the tubular expansion cone launcher 20, the tubular shoe 22, and the expandable tubular member 24. In particular, the pressurization of the annular chamber 28 will cause the GuibersonJ cup seal 26 to pull the tubular expansion cone 18 upwardly out of the apparatus 10. Furthermore, the pressurization of the interior 22a of the tubular shoe 22 below the tubular expansion cone 18 will push the tubular expansion cone upwardly out of the apparatus 10. As a result, the tubular expansion cone launcher 20 and the expandable tubular member 24 are radially expanded and plastically deformed.

In an exemplary embodiment, during the radial expansion and plastic deformation of the tubular expansion cone launcher 20 and the expandable tubular member 24, the fluidic material 32 is conveyed through the radial passages, 18ca,

18cb, 18cc, and 18cd, into the annulus 34 defined between the conical exterior surface 18d of the tubular expansion cone 18 and the interior surfaces of the tubular expansion cone launcher 20 and/or the expandable tubular member 24. As an unexpected result, the tubular expansion cone launcher 20 and/or the expandable tubular member 24  
5 hydroplane on the conical outer surface 18d of the tubular expansion cone 18 during the radial expansion and plastic deformation of the tubular expansion cone launcher and expandable tubular member. During exemplary experimental testing of the apparatus 10, the unexpected hydroplaning of the expansion cone launcher 20 and/or the expandable tubular member 24 hydroplane on the conical outer surface 18d of the  
10 tubular expansion cone 18 during the radial expansion and plastic deformation of the tubular expansion cone launcher and expandable tubular member provided the further unexpected result of reducing the operating pressure of the fluidic material 32 required to radially expand and plastically deform the tubular expansion cone launcher 20 and/or the expandable tubular member 24. In an exemplary experimental test of the  
15 apparatus 10, the operating pressure within the annulus 34 was approximately equal to the operating pressures within the apparatus 10 below the tubular expansion cone 18 and within the annular chamber 28.

As illustrated in Fig. 3, the curve 100 illustrates typical required operating pressures of the fluidic material 32 in order to radially expand and plastically deform the  
20 tubular expansion cone launcher 20 and/or the expandable tubular member 24 for a range of angles of attack of the conical outer surface 18d of the tubular expansion cone 18. As will be recognized by persons having ordinary skill in the art, the angle of the attack of the conical outer surface 18d of the tubular expansion cone 18 refers to the angle of inclination of the conical outer surface relative to the longitudinal direction. By  
25 contrast, the curve 102 illustrates typical required operating pressures of the fluidic material 32 in order to radially expand and plastically deform the expandable tubular member 24 for a range of angles of attack of the conical outer surface 18d of the tubular expansion cone 18 where the radial passages, 18ca, 18cb, 18cc, and 18cd, were omitted from the tubular expansion cone. Unexpectedly, the omission of the  
30 radial passages, 18ca, 18cb, 18cc, and 18cd, from the tubular expansion cone 18 of the apparatus 10 significantly increased the required operating pressures of the fluidic material 32 in order to radially expand and plastically deform the expandable tubular member 24 across the range of angles of attack of the conical outer surface 18d of the tubular expansion cone 18. Thus, the unexpected hydroplaning of the expansion cone

launcher 20 and the expandable tubular member 24 hydroplane on the conical outer surface 18d of the tubular expansion cone 18 during the radial expansion and plastic deformation of the tubular expansion cone launcher and expandable tubular member provided the further unexpected result of reducing the operating pressure of the fluidic material 32 required to radially expand and plastically deform the tubular expansion cone launcher and/or the expandable tubular member.

In an exemplary embodiment, as illustrated in Fig. 4, after completing the radial expansion and plastic deformation of the tubular expansion cone launcher 20 and the expandable tubular member 24, the expandable tubular member is coupled to the interior surface of the borehole 12.

It is understood that variations may be made in the foregoing without departing from the scope of the invention. For example, the teachings of the present illustrative embodiments may be used to provide a wellbore casing, a pipeline, or a structural support. Furthermore, the elements and teachings of the various illustrative embodiments may be combined in whole or in part in some or all of the illustrative embodiments. In addition, the tubular expansion cone 18 may include one or more radial passages 18c extending from the longitudinal passage 18b to the exterior surface of the tubular expansion cone. Furthermore, the apparatus may include one or more GuibersonJ cup seals 26.

Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. Accordingly, it is appropriate that the appended claims be construed broadly.

## **CLAIMS**

1. An apparatus for radially expanding and plastically deforming a tubular member, comprising:
  - 5 a tubular support member that defines a longitudinal passage;  
an expansion device coupled to an end of the tubular support member that defines a longitudinal passage and one or more radial passages that extend from the longitudinal passage and extend to an outer surface of the expansion device;
  - a tubular expansion launcher that receives the expansion device;
  - 10 an expandable tubular member coupled to an end of the tubular expansion launcher; and  
one or more cup seals coupled to the tubular support member for sealingly engaging the interior surface of the expandable tubular member.
- 15 2. The apparatus of claim 1, wherein the expansion device comprises a tapered outer surface and a non tapered outer surface; and  
wherein at least one of the radial passages extends to the non tapered outer surface.
- 20 3. The apparatus of claim 2, wherein at least one other of the radial passages extends to the tapered outer surface.
4. The apparatus of claim 1, wherein the expansion device comprises a tapered outer surface and a non tapered outer surface;  
25 wherein at least one of the radial passages extends to the non tapered outer surface; and  
wherein at least one other of the radial passages extends to the tapered outer surface.
- 30 5. The apparatus of claim 1 wherein the expansion device comprises a tubular expansion cone;  
wherein the tubular expansion launcher comprises a tubular expansion cone launcher that receives the tubular expansion cone; and

wherein the apparatus further comprises a tubular shoe coupled to an end of the tubular expansion cone launcher that defines a valveable longitudinal passage.

6. The apparatus of claim 5, wherein the tubular expansion cone comprises a tapered outer surface and a non tapered outer surface; and  
5 wherein at least one of the radial passages extends to the non tapered outer surface.

7. The apparatus of claim 6, wherein at least one other of the radial passages  
10 extends to the tapered outer surface.

8. The apparatus of claim 5, wherein the tubular expansion cone comprises a tapered outer surface and a non tapered outer surface;  
wherein at least one of the radial passages extends to the non tapered outer  
15 surface; and  
wherein at least one other of the radial passages extends to the tapered outer surface.